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Relaxed $+G_z$ tolerance in healthy men: effect of age

DAVID H. HULL, ROGER A. WOLTHUIS, K. K. GILLINGHAM, AND JOHN H. TRIEBWASSER
Internal Medicine Branch, US Air Force School of Aerospace Medicine, Aerospace Medical Division, Brooks Air Force Base, Texas 78235; and Medical Division, PARAF Hospital, Wroughton, Wiltshire, United Kingdom

HULL, DAVID H., ROGER A. WOLTHUIS, K. K. GILLINGHAM, AND JOHN H. TRIEBWASSER. *Relaxed $+G_z$ tolerance in healthy men: effect of age.* J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 45(4): 626-629, 1978.—Fifty-three healthy US Air Force aircrewmen, 25-55 yr old, volunteered for a centrifuge study designed to determine the effect of age on relaxed $+G_z$ tolerance. Each was subjected to G forces of gradual and rapid onset, with G tolerance determined by standardized contraction of peripheral visual fields. Of the subject characteristics studied, only age was positively correlated with rapid-onset G tolerance; both age and weight were positively correlated with gradual-onset G tolerance. A combination of age and weight gave a stronger positive correlation with G tolerance (rapid- and gradual-onset) than did either characteristic alone. No significant negative correlations were observed. We conclude that aging may offer some protection from G stress; there is no evidence that aging leads to a decrement in G tolerance.

aging; acceleration; G stress

IMPROVEMENTS in general health and life expectancy have led to an increase in average age of the working population in most western countries. This in turn has stimulated research into age-related alterations in work capacity, and into the effects of age on responses to various forms of stress. For example, there is a measurable decrement in aerobic exercise capacity with increasing age (11). On the other hand, orthostatic tolerance in healthy men is unimpaired even in the senium (8). Surprisingly, we know almost nothing about the effect of aging on acceleration tolerance; published studies have used younger subjects exclusively (2, 7).

Information about the effect of aging on acceleration tolerance has relevance to many current and planned aerospace programs. In the civilian sector, for example, supersonic transport and the space shuttle may expose the older individual to G forces not previously experienced, and his response cannot be predicted. Concurrently, in the field of high-performance aviation, the mean age of our test pilot, military aircrew, and astronaut populations is steadily increasing, and the effect of aging on their acceleration tolerance is unknown, though thought to be small.

The present study was designed to examine the relationship between age and relaxed (nonstraining) acceleration tolerance in military aircrewmen. The effects of straining maneuvers and/or G stress inexperience on G tolerance were not evaluated in this study. Such knowledge, though pertinent, requires further research.

METHODS

All subjects were active duty US Air Force pilots or navigators who volunteered for the study shortly after passing their annual Flying Class II medical examination (i.e., fit for unrestricted flying of any aircraft). Subjects were selected by 5-yr age groups to obtain an approximately uniform age distribution between 25 and 55 yr. No subject was taking antihypertensive or other medication. One subject had long-standing asymptomatic right bundle branch block, but organic heart disease had been excluded by investigations which included cardiac catheterization and coronary angiography. Table 1 gives further details of the subjects.

Centrifuge tests were conducted at the US Air Force School of Aerospace Medicine (USAFSAM) Human Centrifuge Facility, Brooks AFB, Texas. Testing took place in the early afternoon, at least 2 h after the last meal. Centrifuge gondola temperature was maintained in the range 22-24°C. The subject sat in a standard aircraft ejection seat with a seat back angle of 13° from the vertical; no anti-G suit was worn. Continuous television and ECG monitoring accompanied each test. A detailed pretest briefing emphasized the importance of muscular relaxation during each centrifuge run; inadvertent straining was seen as muscle artifact (EMG) on the ECG monitor and was quickly corrected by reminding the subject to relax.

Relaxed (nonstraining) G tolerance[1] end points were identified by the occurrence of 100% peripheral light loss (PLL) or of 50% central light dimming (CLD); PLL and CLD were assessed as follows. The subject fixed his gaze on a red light mounted centrally on a horizontal bar at eye level; two green lights mounted symmetrically at each end of this bar subtended an angle of 50° with the bridge of the subject's nose. The central red light was continuously illuminated; the peripheral green lights were turned on frequently and randomly

[1] G tolerance refers to $+G_z$ tolerance in this report.

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by the centrifuge operator and promptly switched off by the subject with a handheld switch. A run was halted *a*) by the subject when he became aware of PLL or CLD, or *b*) by the centrifuge operator if the subject failed to switch off the peripheral green lights within 2 s of their being illuminated.

The centrifuge test (Fig. 1) began with a gradual-onset run (GOR) in which $+G_z$ force was increased at a rate of 0.067 G/s to a possible maximum of 6 G. This first GOR was considered a "familiarization run," designed to allay apprehension associated with the centrifuge environment. Next followed a succession of rapid-onset runs (ROR's). Each ROR consisted of the rapid imposition of G force (increased by 1.0 G/s) to a predetermined level (2.5 G for the first ROR), which was maintained for 15 s. ROR's at progressively higher plateaus were repeated until the visual end point occurred; the G level of that run was recorded as the subject's ROR tolerance limit. Finally, a second, definitive GOR was accomplished and these data were used as the subject's gradual-onset G tolerance. All centrifuge runs were separated by intervals of 20 s or more.

Results of the ROR and definitive GOR for each subject along with age, height, weight, exercise habits, and recent and total flying experience were entered into

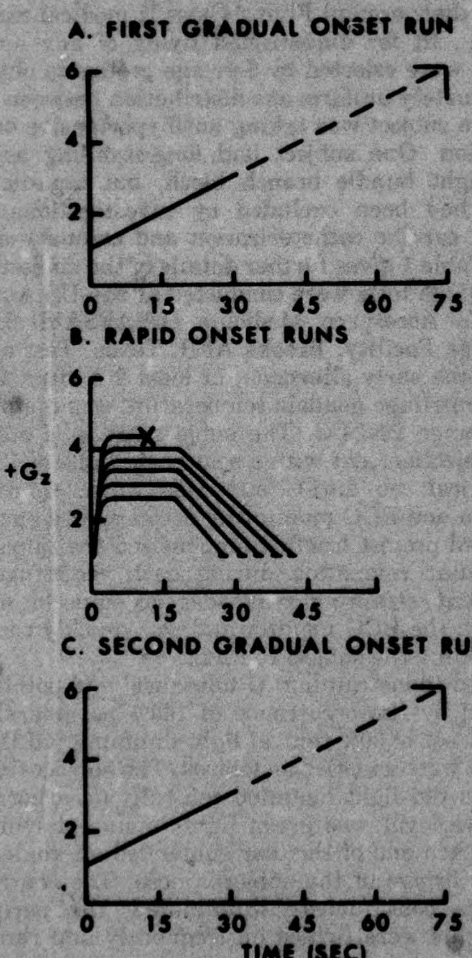

FIG. 1. Centrifuge protocol.

a computer. Standard statistical methods were used for all subsequent analyses.

RESULTS

Effects of age alone. Mean subject data for all age groups are shown in Table 1. Use of age groups ensured a uniform age distribution except for a shortage of subjects in their 50's (reflecting the age structure of active duty US Air Force flyers). Mean height and mean weight were similar across the age groups. On the other hand, total flying experience increased with age, whereas flying experience during the previous 6 mo showed a corresponding decrease. This is the extent of our analysis by age group; all subsequent analyses are for the total sample of subjects ($n = 53$).

Least-squares regressions of ROR tolerance on age and GOR tolerance on age were completed (Figs. 2 and 3). There was a significant, positive relationship between age and G tolerance ($P < 0.05$ for ROR and GOR), despite substantial variability and the modest inclination of regression slopes. We concluded that increasing age probably confers some protection against the effects of unresisted G forces, and certainly causes no decrement in G tolerance.

We note in passing that the GOR protocol automatically stopped at 6 G. As shown in Fig. 3, three subjects reached this 6-G level before sensing PLL or CLD; the stated GOR tolerance for these individuals is thus artificially low. We feel, however, that the effect of understating their GOR tolerance on the overall regression analysis is of no practical importance.

Other variables. Correlation coefficients were computed for G tolerance versus each of the several variables shown in Table 2. There were only four statistically significant correlation coefficients, and all four were relatively weak. For ROR tolerance, the only significant correlation was with age. On the other hand, GOR tolerance was significantly correlated not only with age, but also with weight and with total flying experience. This latter correlation is not surprising since total flying experience is itself highly correlated with age ($r = 0.84$, $P < 0.001$); on the other hand, weight and age were not correlated. These observations are supported by the data in Table 1. We conclude that age is equal to or better than any other single variable tested for predicting relaxed G tolerance.

We also tested to see whether combinations of variables might better predict G tolerance. We used a stepwise multiple regression analysis for this purpose. There was no evidence that ROR tolerance prediction

TABLE 1. *Mean data for subjects in each age group*

	Age Group, yr					
	25–29	30–34	35–39	40–44	45–49	50–55
n	10	11	10	9	10	3
Ht, cm	183	181	178	181	180	176
Wt, kg	80	80	80	86	79	81
Total flying experience, h	1,607	2,573	3,071	4,644	5,050	6,633
Last 6 mo flying experience, h	142	106	43	4	11	0

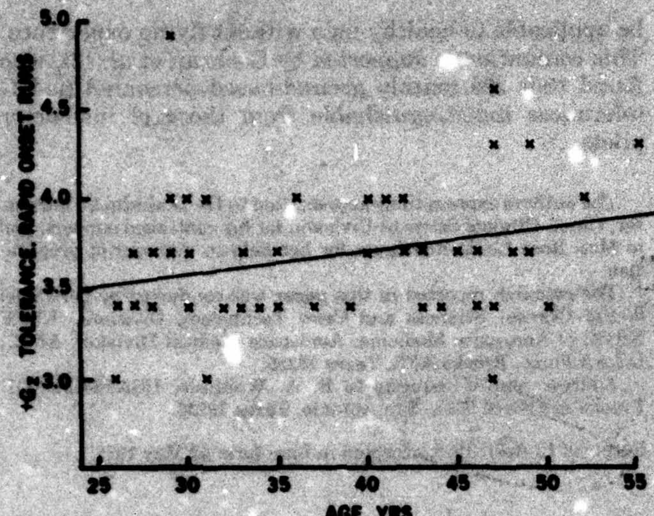

FIG. 2. Relationship between ROR G tolerance and age is shown. Some points represent more than one subject ($n = 53$). $r = 0.27$, $P < 0.05$, $Y = 3.18 + 0.013X$, SEE = 0.38.

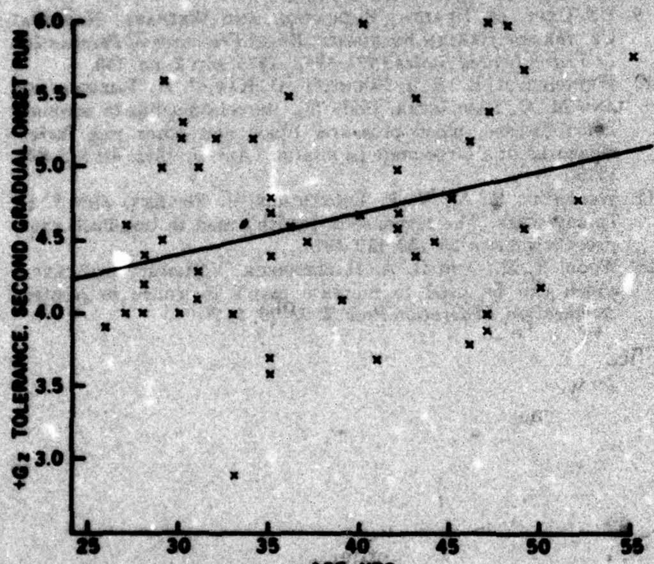

FIG. 3. Relationship between GOR G tolerance and age is shown. Some points represent more than one subject ($n = 51$). $r = 0.31$, $P < 0.05$, $Y = 3.60 + 0.028X$, SEE = 0.66.

TABLE 2. *Variables studied in relation to G tolerance*

	Age	Ht	Wt	Aerobic Exercise	Body Building Exercise	Total Flying Experience	6-mo Flying Experience	Seated SBP	Seated DBP
ROR	0.27	–	–	–	–	–	–	–	–
GOR	0.31	–	0.25	–	–	0.29	–	–	–

Correlation coefficients shown were statistically significant ($P < 0.05$); other relationships (–), not statistically significant.

could be statistically improved by using more than the age variable alone. GOR tolerance prediction was significantly improved by adding weight to the age model ($P < 0.05$, GOR tolerance = 1.3 + 0.025 age + 0.030 weight, SEE = 0.64); no other variable contributed significantly over and above age and weight.

DISCUSSION

Study of relaxed subjects. We studied the G tolerance of relaxed subjects because it represents the innate human response to G stress under standardized physiological conditions. The complex interaction of several largely uncontrolled variables which is introduced when G forces are resisted by voluntary effort and by anti-G protection devices, is thus avoided. There appears to be some relationship between relaxed and straining G tolerance, but this relationship is not consistent (1).

Age and G tolerance. The main object of the study was to determine the effect of age on the G tolerance of relaxed healthy men. Age has rarely been considered in acceleration research; many definitive studies (2, 3, 7) have been carried out where nearly all military aviators were young men. Cochran et al. (2) compared G tolerance of experienced naval aviators with that of cadets and concluded that age had no effect on G tolerance, a view that has been accepted (5, p. 577). Both Cochran et al. (2) and Rose and Martin (7) reported a very wide range of G tolerances, which may in part have been due to variations in experimental technique and in the use and effectiveness of the straining maneuvers employed by their subjects. Such factors would almost certainly efface the modest age-related trend apparent among our subjects, in whom all conditions were as carefully standardized as was possible.

G tolerance and body measurements. Neither Cochran et al. (2) nor Rose and Martin (7) could detect any relationship between stature or weight and G tolerance. However, it is commonly believed that tall men are at a disadvantage under G stress, since their retinal and cerebral circulation must depend on a higher column of blood than that in a shorter individual. Hunter (6) found that the blackout threshold was related to sitting height and to heart-brain distance.

The height of our subjects was unrelated to their G tolerance, but their weight had an effect that was comparable to that of age. None of our subjects was more than mildly obese. Our results, therefore, suggest that G tolerance is positively related to heaviness of build. It is of interest that body-building exercise improves resistance to G forces (straining tolerance) (4); we found no such relationship with relaxed G tolerance in the present study.

Influence of related factors. Our analysis has certainly not established a causative role for age or weight in determining G tolerance, and both variables are likely to be related to other unmeasured factors of greater physiological relevance. One such factor of obvious importance is arterial blood pressure (BP) (12) which rises during adult life (9) and is also related to body weight (10). Though our subjects were clinically normotensive (BP < 140/90 Torr) and though their casual clinical systolic and diastolic BP's were apparently unrelated to G tolerance, the actual BP during centrifuge runs could have risen more in older than in younger subjects. Unfortunately, invasive techniques, themselves almost certain to influence the responses they measured, would have been required to confirm this. Other age-related factors possibly affecting G tolerance, such as rigidity of blood vessels (5, p. 565) or

limitation of diaphragmatic descent (5, p. 583) would be even harder to measure.

General applicability of results. Because the subjects were all experienced military aircrew members, the applicability of our findings to other fit men of comparable age may be questioned. In this regard, some of our negative findings may be important. Whereas total flying experience correlated positively with G tolerance (but only to GOR tolerance), recent flying experience was negatively correlated, though not significantly. However, although flying experience was strongly correlated with age, it appeared to have no effect on G tolerance in our stepwise multiple regression analysis. If flying experience can be ignored as a factor in the relaxed subject's G tolerance, then the profession of our subjects may have little relevance and our results may be applicable to healthy men without flying experience. This contention is supported by Cochran et al. (2), who found that 293 mainly ground-based personnel had G tolerances indistinguishable from those of instructor pilots.

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Address reprint requests to R. A. Wolthuis, USAFSAM/NGI, Brooks Air Force Base, San Antonio, Texas 78235.

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Fifty-three healthy USAF aircrewmen, 26—55 years of age, volunteered for a centrifuge study to determine the effect of age on their relaxed $+G_z$ tolerance. They were subjected to G forces of gradual and rapid onset, G tolerance being determined by a standardized contraction of peripheral visual fields. Of the subject characteristics studies, only age correlated with rapid onset G tolerance, while age and weight correlated with gradual onset G tolerance. A combination of age and weight gave a better correlation with G tolerance (rapid- and gradual-onset) than did either characteristic alone. We conclude that

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